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Evaluation of the Performance of Human Operators as a Function of Ship Motion

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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Washington, D.C. 20007

NAVAL SHIP RESEARCH AND DEVELOPMENT LABORATORY
Annapolis, Maryland 21402

EVALUATION OF THE PERFORMANCE OF HUMAN OPERATORS AS A FUNCTION OF SHIP MOTION

An Engineering Psychology Study
Aboard the USS GLOVER (AGDE 1)

By
F. Warhurst and A. J. Cerasani

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ABSTRACT

This study examines in an operational setting the hypothesis that human performance is significantly affected by ship's roll. Particular attention is paid to the nature and effects of roll stabilization equipment. The hypothesis is expanded to include the broad spectrum of human performance and the more subtle aspects of ship's motion.

Notable findings include:

- Ship motion causes an irrelevant stress on crew members.

- Some irrelevant stress may actually be beneficial.

- The effect of roll stabilization equipment is diphasic; it reduces intolerable roll amplitudes but tends to induce higher linear accelerations.

- Roll stabilization should be active from dead-in-water through flank speed since mission requirements include extensive operations at low speeds.

ADMINISTRATIVE INFORMATION

This report covers a component of the work accomplished under Sub-project S4627-020, Task 13694, that is being coordinated by NAVSEC (SEC 6165C4). The work was done under Assignment A624-150.

ACKNOWLEDGMENTS

The help of Dr. G. Wendt and Dr. J. Cameron of the University of Rochester for their instruction in and permission for the use of the Adjective Checklist is appreciated.

The officers and crew as well as civilian personnel and liaison officers aboard the USS GLOVER (AGDE1) were especially insightful and cooperative in support of this experiment.

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INTRODUCTION

It is well known that some vehicular motions cause individuals to become ill; the symptoms are faintness, dizziness, sweating, sleepiness, and nausea. The medical name for the condition so caused is "kinetosis," but it is commonly called "motion sickness" or "seasickness." The performance level of a sufferer of acute kinetosis is understandably lowered; he may be unable to perform at all.

For purposes of this study, however, we are not concerned with the performance of subjects exhibiting such symptoms. Our assumption is that, even though the subject is not sick (as shown by observation and subjective report), his performance may be altered by the fact that he is subjected to vehicular motions. It is obvious that the motion of a ship degrades the performance of a man performing a task where mass, balance, and accelerations are the key parameters (carrying a heavy weight, balancing on a narrow platform, traversing a wet slippery deck). This investigation is aimed at determining the more subtle effects on performance resulting from long-time exposure of the subject to such motion.

There are many equipment-design solutions to motion-induced difficulties aboard ship (handholds, high-friction deck surfaces, raised edges on work-table surfaces). Many of these solutions have been used aboard ships for thousands of years and many others could and should be devised. However, these represent attempts only to cope with motion in gross motor tasks and may have little or no effect on fine-motor and cerebral tasks.

The use of whole-ship roll- and pitch-stabilization equipment promises to eliminate undesirable motion effects through partial elimination or alteration of ship motion about two horizontal axes. We limit our concern here to roll-stabilization apparatus such as that found on the USS GLOVER (AGDE 1).

Roll-stabilization gear on the GLOVER consists of two oarlike planes protuding at a depressed angle from the chine line, one on each side about amidships. Each is powered by electrohydraulics, controlled by sensors tied into the ship's gyros. The control input is modified so that the oars are oriented with respect to the water through which they are moving to provide dynamic forces which limit rolling; the system does not attempt to keep the ship vertical. Hull-through-the-water speeds of less than about 12 knots are insufficient to provide significant roll-limiting moments by this means. Within the design performance envelope (12 to 29 knots) this equipment does reduce the maximum amplitude of the roll. However, its effect is not merely that of partial elimination but rather of alteration also; momentary lateral accelerations resulting from roll may actually be increased at points not on the roll axis of the ship. Alterations to other natural motions of the ship (pitch, heave, yaw) are suspected but unconfirmed.

The theoretical hypothesis to be tested by this investigation is: Human performance is significantly affected by ship roll.

APPROACH

An attempt was made in this study to use all three major methods of engineering psychology: phenomenological observation, correlation of cause-and-effect related events, and pure experiment involving the manipulation of an independent variable and the recording of the dependent variable. Furthermore, immediate performance measures, both quantitative and qualitative, and an inferential measure of performance motivational level were used.

Phenomenological observation requires the gathering, without manipulating the environment, of data in the form of unquantified particulars. These data may be of events directly observed by the experimenter or may be reported to him by individuals in a position to make direct observation. The trained experimenter (E) practices a gross discrimination in choosing what is recorded and what is not; for example, he does not record the anomalistic behavior of a subject (S) if S is influenced by a stimulus obviously unrelated to the one in question. On the other hand, all departures from the norm, in the absence of causes judged unrelated to the cause in question, must be recorded. The events within themselves may contain qualitative measures such as "easy, difficult, very difficult" when referring for instance to how a certain job was affected by ship motion. When the data have been gathered and results are tabulated, certain trends may be seen which are not apparent from cursory observation. Just as important, certain trends which seem to be apparent from cursory observation may be dispelled. Important conclusions may be drawn from the relative absence of abnormal events in the presence of the variable in question.

In using the method of correlation to test a hypothesi , quantitative data concerning events which are judged to be, based on pilot analysis, a function of the variable in question are taken. It is, of course, intrinsically important with this method that the variable in question does in fact vary and that other unspecified variables which may affect the data remain small or randomize out. It is entirely possible that any particular causal variable will be masked by noise. Since the problem of human performance as a function of ship motion is complicated, the use of the correlational method demands relatively large numbers of subjects and trials in order to assure randomization of uncontrolled variables. The data so collected are tabulated and treated mathematically to determine correlational values which imply a causal relationship between, in this case, ship motion and human performance.

The experimental method is the most precise and provides, therefore, the basis for making the most valid conclusions in testing the experimental hypothesis. It involves manipulation of the independent variable (ship roll in this case) by the experimenter according to a schedule designed to control or eliminate the effects of unwanted variables. In the present case, examples of unwanted variables are: length of time at sea, time of day, practice effects in repetitive tasks, order of presentation of several tasks, length of exposure to any particular intensity of roll, time of test within S's work period. This method requires considerable control over the environment and the subjects.

LIMITATIONS

The theory underlying a consideration of this problem must suit the real-world circumstances. In particular, the theoretical hypothesis stated in the introduction must be made less general in three respects.

First, the USS GLOVER, aboard which this investigation was conducted, is not the "universal ship." It might be called typical, but such vessels as LST's,* which are even longer, are said to roll, pound, slam, and heave more than it does. Second, immediate observations were possible only of personnel exposed to the ship's motion for a single 2-week cruise. However, it is evident that a more stringent requirement of up to 30 days of violent motion would be more realistic for the investigation of this question. While this condition may be rarely met, the high reliability demanded by the system of which these warships are a part requires design for this contingency. Third, circumstances of the cruise dictated against pure examination of roll versus no-roll. Consequently, the question involves roll versus roll with roll stabilization, each with respect to human performance levels under no-roll conditions.

*LST = Landing Ship, Tank

METHODS

Throughout the cruise, the experimental team collected phenomenological data by personal oral and written interview and data on motivational levels by the questionnaire method. After the initial orientation, three particular repetitive tasks were chosen from which to collect quantitative data on a "whenever-possible" basis. The recording of roll at times when immediate data were being recorded was handled by the Shipboard Instrumentation Center personnel augmented by direct observation of the clinometer at other notable times.

Phenomenological data were gathered and recorded by the experimental team almost continuously. The team toured all spaces of the ship from keel to topmast looking for procedures and equipment configurations and arrangements designed to facilitate work in a moving environment. Areas not routinely frequented were visited often in order to accustom the crew to the team's presence and thus reduce the artificial behavior which sometimes results from the presence of an observer. These data were later distilled and organized, and summaries appear in the Results section.

The Critical Incident and Adjective Checklist questionnaire, together with an information sheet and vocabulary list, comprise Appendix A. They were handed out as a package to each subject early in the cruise and supplemented by oral instructions. Copies of the questionnaire, alone, were passed out and collected many times during the cruise. The particular areas and particular times selected were the galley, bridge, combat information center (CIC), sonar control space, boiler room, engine room, and executive office, usually at the end of watch periods. Roll was recorded on each occasion and later matched with responses during data reduction.

The Critical Incident section is self-explanatory. The Adjective Checklist measure of mood was developed by Dr. G. Wendt of the University of Rochester and has proved highly reliable in measuring mood as a function of various stimuli.

For the experimental method, three particular repetitive tasks which were chosen to evaluate human performance were the boiler feedwater analysis task, the typing task, and the plotting task. These tasks were observed and evaluated during various watch periods and, if possible, performed by different individuals. Table 1 shows these variables.

Table 1
Tasks Evaluated for Human Performance

	Boiler Feedwater	Typing	Plotting
Number of Subjects	1	3	7
Number of Trials	11	10	7

1. Boiler Feed Water Analysis Task

a. Purpose and Procedure for this Task. The GLOVER is powered by steam turbines. A virtually closed system boils the water, superheats the steam, routes it to the turbines, condenses, and recycles it. The small loss is made up by distillation of seawater and added to the "feedwater" part of the system. Because of the chemistry of the system, chemical contaminants are present in the system water. (Contaminants cause premature failure of the mechanical parts in the system as a function of concentration and time.) Therefore, any such system must be tested chemically on a regular basis, daily in this case, and "doused" (corrective chemicals added) if necessary to restore the desired chemical balance.

Each morning a boiler technician petty officer (BTPO) draws samples of the feedwater. The first sample is drawn from the main active system in such a way that its temperature can be controlled. The sample bottle is removed to a chemical analysis bench. A portion is filtered. Subportions are used to determine the pH, phosphate, and chloride levels. These tasks involve the use of specialized sample graduates, the introduction by the drop-counting or graduated burette methods of color indicators, and color-matching with standard solutions.

Sources of error include contamination of the sample because of careless procedures, misjudging of the miniscus, miscounting the drops, misreading the graduate, and mismatching of colors. Roll contributes directly to error through the physical difficulty of "clean" pouring while rolling and through change in the position of the miniscus with respect to the graduations being read.

b. Feedwater Task Evaluation Procedures.

(1) The individual subject available for this test was a BT3c. He was instructed to proceed normally being careful only to avoid interruptions from other persons during the task.

(2) A time measure was made of each subtask (four, including clean-up time).

(3) A quality-of-work (accuracy) measure was made by having a more experienced man run the same samples at a later time.

(4) The roll of the ship was recorded.

2. Typing Task

a. Purpose and Procedure of this Task. A great deal of typing is done aboard a naval vessel both in the Radio Communications Center and in the Ship's Office. A typing task involves manipulation and eye-tracking, both of which are affected by vestibular disturbances caused by an unsteady environment. This Task is representative of the innumerable data logging and communique tasks that occur during every ship mission.

A master test page was constructed consisting of a 15 X 15 matrix of capitalized three-letter "Q" signals (e.g., QKZ, QJT, QMF, etc) obtained from the ship's communications handbook and reading at the top:

b. Typing Task Evaluation Procedures.

(1) Subjects were three yeomen assigned to the Ship's Office.

(2) Tasks were administered daily under fairly well controlled conditions whenever the schedule permitted on a noninterference basis.

(3) Roll was recorded.

3. Plotting Task

a. Purpose and Procedure for this Task. Routine operation of the GLOVER requires the bridge to be well aware at all times of other surface vessels in her vicinity in order to avoid collision. This requirement is met by visual scanning of the sea surface, by observation of the surface radar screen on the bridge, and by more detailed information supplied orally to the bridge by CIC personnel. A CIC radar screen observer detects targets, determines their range and relative bearing, assigns identification, and transfers this information orally to a plotter. The plotter, working with a dead reckoning table (DRT), plots the information with pencil and paper together with ship's own course (SOC) and thus generates a true path which can be read with the PMPR (drafting machine and scales) to determine target true course, speed, and closest point of approach (CPA). This information is then communicated to the bridge orally on demand. A two-man team may handle in excess of 20 targets simultaneously (each delineated by points numbering from 2 to N), upgrading and refining the determinations, noting change of course and speed of the target or own ship or both, sometimes changing paper or the location of the zero point in order to keep their plot within the range of the DRT, and scratching targets of no further interest. Since the timeliness and accuracy of this task is vital to ship safety, this procedure (sometimes complicated further by air and subsurface targets) can be highly stressful. Since it involves transmission of data orally, scale-reading for input and output, low light-level conditions, a fairly high noise level and "distracting" environment, vigilance and short-term memory, it is a good measure of human performance levels.

b. Test materials, Subjects, Evaluation Procedures.

(1) A T3 AN/SPS Trainer/Radar Target Simulator was programmed to present on the appropriate scope face six targets within practicable range for the DRT at various bearings and at various realistic surface speeds.

(2) Subjects were six experienced enlisted men operating in teams of two according to their availability. The CIC room proved to be a well stabilized environment when it was available (usually during the 0000-0600 period). Despite the fact that the test required the presence of an extra man who would ordinarily be sleeping, the subjects seemed well motivated, interested in their work, and cooperative. Initially there was a great deal of difficulty with the erratic behavior of the T3, but it later gave consistent performance.

(3) The data were taken according to the realistic procedure outlined in 3.a. above, beginning with the announcement of a target by the scope observer and ending with the announcement of a course and speed by the plotter. The targets were handled one at a time, and the SOC varied between trials to vary the task particulars. A time measure (in seconds) and an accuracy measure (in degrees and knots) are the performance measures. Certain gross errors are also observable on the plotting sheets but are not subject to statistical analysis.

RESULTS

The results of the motivational and critical incident questionnaires are summarized in Figure 1.

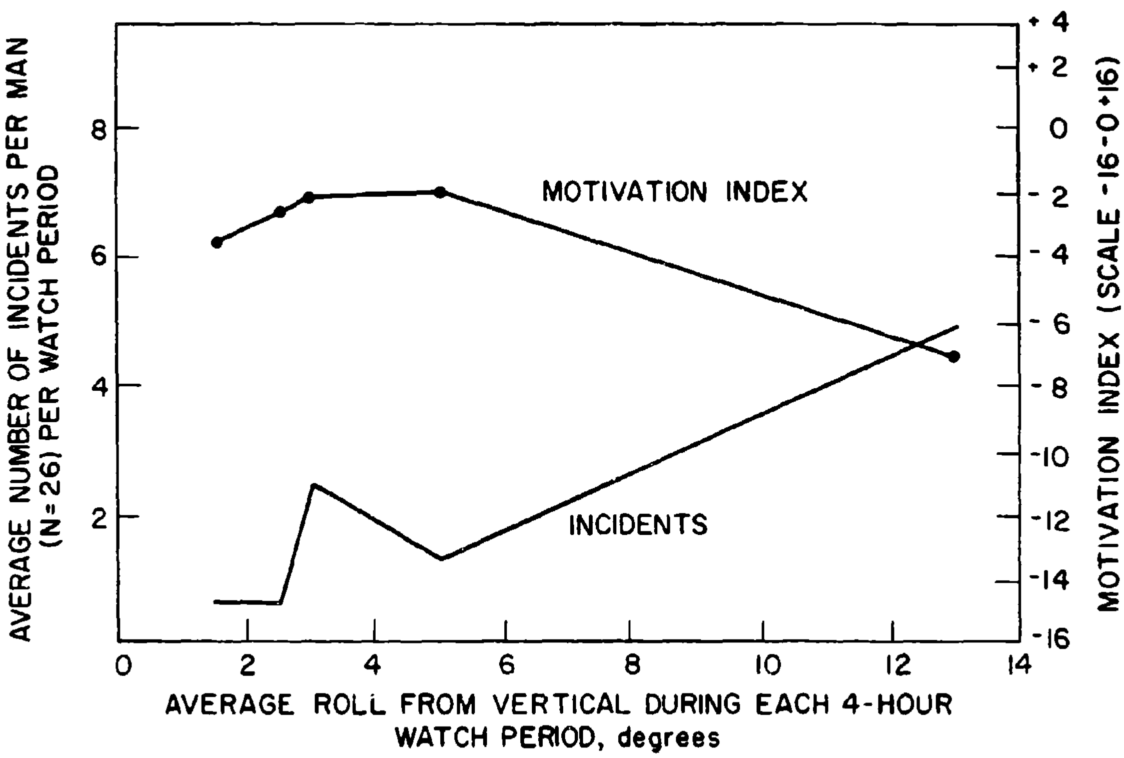

Figure 1
Roll-Caused Incidents and Motivation Index as a Function of Ship's Roll

Obviously there are too few points to justify, mathematically, the curve which has been drawn in; the graph is intended merely as a presentation device and will be discussed in the next section. The sort of incident being counted includes falls, stumbling, mistakes in judgment, spilling or dropping of materials, difficulty in handling tools which resulted in damage or injury, and mechanical mishaps which resulted from failure to anticipate the effects of roll on the movement of equipment. The motivational measure is based on an arbitrary scale developed during research in other areas.

The three quantitative performance test results were such that no valid mathematical treatment was possible. The reasons for this appear in the Discussion and Critique section. A number of useful observations were made possible by the test situations, however, and appear with the other observations in this section.

The results of phenomenonological observation and interview appear below. Not all incidents are reported since they are too numerous and redundant. Qualitative phrases are used to indicate relative importance and frequency. The incidents listed are severely restricted to those which are obviously related to ship roll. Those observations generally of interest to the engineering psychologist team will appear in a technical note (to be published) and indicate how other specific items on shipboard contribute to altered human performance capabilities irrespective of ship motion.

The resultant findings, summarized in Table 2, are as follows:

- Companionway lights jut out from the bulkheads at frequent intervals. They are so placed and configured that they are struck by the legs of persons negotiating the passageway, expecially during heavy roll conditions. These were often located close to doorways, resulting in an aggravation of the already existing traffic problem at these points.

- One of the subtasks performed during the water analysis task required the operator to stand on a small stool. His position was precarious and resulted in several minor falls during the trials.

- No preference was expressed by typists for orientation of their machines with respect to the roll axis.

- Seated radar operators, located high in the ship, preferred chairs with arms to those without.

- Complaints were heard regarding the lack of restraint devices on the "new" bunks which could not be loosened to prevent rolling out under heavy roll conditions.

- Radar operators were usually rotated to other jobs every hour under low, and every 1/2 hour under high, roll conditions (high = greater than 10°).

- Personal danger to deck personnel increased greatly as a function of roll and proximity to the sea surface.

• During heavy roll, many deck surfaces on the weather decks and inside were wet due to tracking water through doors and due to spillage of various fluids. Some of these surfaces are not skidproofed and offer very poor footing.

• The ship's machinist commented that certain roll conditions caused warpage of the deck to which his lathe was fixed and resulted in warpage of the lathe bed itself and consequent inaccurate and sometimes dangerous operation of the tool.

• Sleep disturbance was often reported as an important negative result of heavy roll.

• The "jolt" resulting from the corrective forces of the roll stabilization gear was especially disruptive in spaces removed from the roll axis.

• Both fine and gross motor tasks were made more difficult under any roll condition but were virtually shut down above a 15° roll. This was especially true of electronic or electrical maintenance because of the shock danger and the size and configuration of the parts.

• Such necessary ship services as the galley and the laundry restricted their operation at a 10° roll and secure operation if possible at 15°. Galley fires have been started by grease spilled by rolling.

• Visual contact, expecially by binoculars, was more difficult to maintain as roll increased.

• Certain pumps tended to lose prime under heavy roll conditions. This increased the need for vigilance by the pump tender.

• Special procedures and devices were necessary at designated work spaces when such small tools as pencils and screwdrivers were in use. At nondesignated places such objects frequently must be retrieved after rolling away.

• Some electronic test gages were sensitive to very low accelerations on the instrument case such as would be caused by ship motion.

• Untrue soundings resulted from fluid motion in storage tanks.

• In general, "one hand for the ship and one hand for self" was the rule.

• Inaccuracies in placing plotting points and in scribing lines through points were seen to result from roll motion and from the jolt resulting from the righting forces of the stabilization gear.

• The effects of roll coupled with improper panel and control design caused inadvertent operation of a start/push button on a sonar control console. This resulted in destruction of $75.00 worth of fuses in a particular case.

Table 2
Summarized Findings of Equipment and Personnel Considerations Resulting From Roll

Roll Condition Degrees	Personnel Behavior or Performance Areas			
	Locomotion and Material Transport	Fine Motor Tasks	Gross Motor Tasks	Motivational and Mood Level of Personnel
0	Normal	Normal	Normal	Normal
About 4	Near normal	Near normal	Near normal depending on weight & delicacy of equipment	Possibly elevated
4-10	Handholds Traffic impaired Special deck surfaces Additional personnel Additional time	Extra care Steadying devices Tool holders Drawer stops Raised table edges	Additional personnel Additional care Additional time Restraining devices	Some fatigue over long periods
Above 10	Difficult to impossible depending on weight, delicacy of load, condition of work space, & feasibility of using additional manpower	Equipment restraints Additional time Additional personnel Extreme care to avoid injury or damage	Extreme care to avoid damage and injury	Lowered morale tiredness, frustration, and fear as result of less sleep, greater physical effort, & consequences of mistakes

DISCUSSION AND CRITIQUE

A discussion of the results of this study must be based almost entirely on the phenomenonological observations made and interpreted through the expertise of the experimental team and consultation with specialists in psychomotor and psychological behavior of personnel in the environment of vehicular motion. Several factors prevented the gathering of statistically valid quantitative data. Because the investigation was conducted on a strict noninterference basis, observations were passive. The number of personnel made available and the times and conditions under which they could be used was limited. But most important, the independent variable in question, roll, was essentially of low value and constant throughout the cruise with the exception of a single 4-hour period. (Said one crewman, "This was the calmest trip we've ever had.") Thus, the conditions necessary for pure or even correlational experiments were not met. While the GLOVER's roll stabilization gear can be controlled manually in order to induce roll, and was in fact manipulated for approximately 30 minutes, the procedure proved so punishing to the stabilization machinery and to primary test personnel and procedures on board that it could not be repeated. Furthermore, during this trip, the shipboard roll instrumentation was not functioning properly and only clinometer readings could be used.

Any roll of 10° or more seriously compromises all shipboard work involving the movement of men and materials; at 20° virtually all nonessential ship's work ceases. The difficulties are compounded with personnel hazards, the weight of unsecured objects, the delicacy of motion required, slippery footing, narrow passages, and other aspects which tend to make shipboard work only marginally possible under calmer nonroll conditions.

There is no doubt that a strong argument can be made for the cost effectiveness of roll-stabilization equipment for ships where roll of greater than 10° is common. For those whose roll never exceeds 10°, however, particularization depending on mission would control the argument.

In the area of medium roll, 4° to 10°, there are two major categories of human performance factors to consider. The first is the purely mechanical factor: How does roll affect a man's ability to perform fine and gross motor tasks? The second is more psychological: Does roll degrade his sensory and perceptual capabilities directly or does his physiological state lower his motivational level thus causing degraded performance?

The mechanical factor is obviously on a continuum. As roll increases so does the difficulty of performing every motor task from walking down a passageway, to doing a delicate soldering task, to lifting a heavy piece of equipment, to keeping one's body in a bunk. Any examination of the cost effectiveness of equipment designed to reduce roll would have to consider what the nature of the prime mission and necessary supporting missions of a vessel would be. It is worth noting that one of the tasks most severely affected by roll aboard the GLOVER, electronic troubleshooting and maintenance, is increasing in importance aboard United States naval ships. Even old ships are being retrofitted with electronic devices which in many cases had no counterpart aboard these vessels before. The shock hazard, smallness of parts, and susceptibility to destruction by inadvertent slippage of probes during a troubleshooting procedure when the ship is rolling become critical in the newer circuitry due to the complexity, sensitivity, high cost, and high-level mission of this equipment.

The mechanical factor also enters into the future manning requirements of naval ships. Many motor tasks require either more time or more manpower, or both, because of roll. Even under roll conditions as low as 4° there is ample evidence that motor behavior is altered; men walking through a door under zero roll (0° to 4°) do so "hands off" while at moderate roll, they find a steadying hand necessary. Fine soldering tasks in moderate roll require extra aids, extra time, and a steadier work stance (gained by leaning the trunk against the workbench perhaps). A worker who needs a hand to steady himself needs another man to fetch or retrieve tools and to hold a flashlight. Strictly in terms of the mechanical factor, the roll of a ship makes work, requires more personnel. Reduction of the amount of roll would allow continuance of some jobs that at present must be halted and the equipment lashed down. It would hardly affect others that now require intermittent stoppage while the equipment is merely held in place or, in the case of tools, simply dropped into their containers. The incidents reported in the Results section depict an inefficient work picture only by inference; an incident represents a departure from the norm but tells very little about what that norm is.

The second category of human performance factors to consider in the area of medium roll is the nonmotor one, the psycho-physical and psychological category.

One aspect of the data, the motivational level versus roll, suggests that a slight amount of roll is actually beneficial. While these data cannot support this idea mathematically, there is a rationale to support it. Roll constitutes what might be called "irrelevant stress"; it is a stimulus calling for a response which is at best irrelevant to the stimulus-response picture in which one is interested. There is a level of irrelevant stress greater than zero which actually facilitates human response to the relevant stimulus. Roll at a level of about 3° to 4° may be this optimal level. However, because of the multiplicity of other irrelevant stresses aboard ship (noise, wind, vibration, improper lighting) and the fact that such motion is very rarely at the zero level, it remains an interesting but academic consideration; no whole-ship roll-stabilization equipment could completely cancel roll.

Above the optimal roll level, fatigue is probably the principal element in psychological impairment. The literature [1,2] indicates that roll-stress, combined with the many other stresses and stimuli on the body, results in sensory and perceptual impairment; eye focus and tracking, for instance, is impaired. It is beyond the scope of this report to examine minutely the mechanisms involved but, in pedestrian terms, simple physiological fatigue best explains what happens. All the consequences of sleep deprivation (which can be a direct result of roll) and excessively long work periods are similar to the consequences of exposure to motion, the performance decrement being a function of time and intensity. It is the opinion of the experimental team, based on observations and consultation with experts in the field of motion studies, that the time and intensity of motion aboard the GLOVER were insufficient to induce the fatigue levels as a separate significant variable in the investigation. In the real world, violent motion aboard naval vessels may continue for 4 to 30 days, with consequent buildup of fatigue levels.

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[1] Fitts, P. M., and M. I. Posner, Human Performance, Chapter 3, Belmont, Calif., Brooks/Cole Publishing Co., 1967

[2] Burns, N. M., R. M. Chambers, and E. Hendler, Unusual Environments and Human Behavior, Chapter 2, London, England, Free Press, Collier-McMillian, Ltd., 1963

One other meaningful difference between zero and moderate roll resulted from this investigation. The roll between 0° and 4° is practically sinusoidal and therefore predictable. But within the operational envelope of roll-stabilization equipment, very definite departures from sinusoidal motion can be felt; these departures are often so strong that they are best described as "jolts." A number of psychomotor incidents directly observed were caused by these jolts. Obviously these abrupt lateral accelerations were more intense in areas of the ship such as the instrumentation room which are far removed from the roll axis, although the frequency of occurrence is the same everywhere. The psychological results can only be inferred, but again, there is reason to believe that the effects of jolt go far beyond the motor impairment level because of the unpredictability of their timing and intensity. As with noise, continuous low-level noxious stimuli are better tolerated than sporadic stimuli.

Roll is stressful to all shipboard personnel. An unpredictably changing environment, especially while performing a task only marginally within the motor capabilities of the performer, constitutes stress, even high stress, depending upon the consequences. Stress is currently one of the most difficult problems in the engineering psychology field. In the case of shipboard roll, it may prove to be the most consequential variable of them all, but because it is so nebulous, it is the most difficult variable to quantify.

CONCLUSIONS AND RECOMMENDATIONS

The hypothesis to be tested, that human performance is significantly affected by roll, is clearly supported by this investigation. Many motor incidents are clearly caused by roll motion. But while this may be evident to the casual observer, the more subtle results of the investigation may not be. They are:

- Lateral accelerations caused by roll-reducing devices may be more harmful to human performance than some greater amount of roll.
- A small amount of roll may be beneficial.
- The true effects of roll are buried in a sea of other ship-specific, irrelevant stimuli including noise, vibration, climate, changing diurnal cycles, and the manning and time norms established for any task.
- There are three distinct regions of human performance along the roll continuum. These regions are 0° to 4°, 4° to approximately 10°, and above 10°. They correspond to ranges at which men can work at various efficiencies, as depicted in Figure 2.
- The effects of roll cannot be said to be simply additive:
  - An intensity of roll which causes a buildup of fatigue may allow unimpaired performance for a given time after which performance may be sharply degraded by an "energy deficit."

. Roll as an irrelevant stimulus, added to other irrelevant stimuli such as poor illumination, may cause a disproportionate drop in performance with relevant stimuli such as perception of an object to be tracked.

. The effects vary according to what part of the continuum is being examined. The ratio of 6° to 3° is not as 30° is to 15°.

• The irrelevant stress of ship roll in the moderate to severe range cannot be treated in the same way that some other human performance factors, such as arm length, are treated. Its effects are not subject to a high degree of quantification. Instead it is more realistically categorized with noise, humidity, temperature, vibration, and other causal factors which are best treated by broader, more qualitative means.

• Below the levels which cause overt nausea, the psychological effects of ship motion may be measurable only through such intermediate forms as motivation level and incidence of somatic illness. I.e., if a subject is unable to perform because of a cold or headache, that somatic ailment could be the psychogenic effect of the variable in question, ship roll.

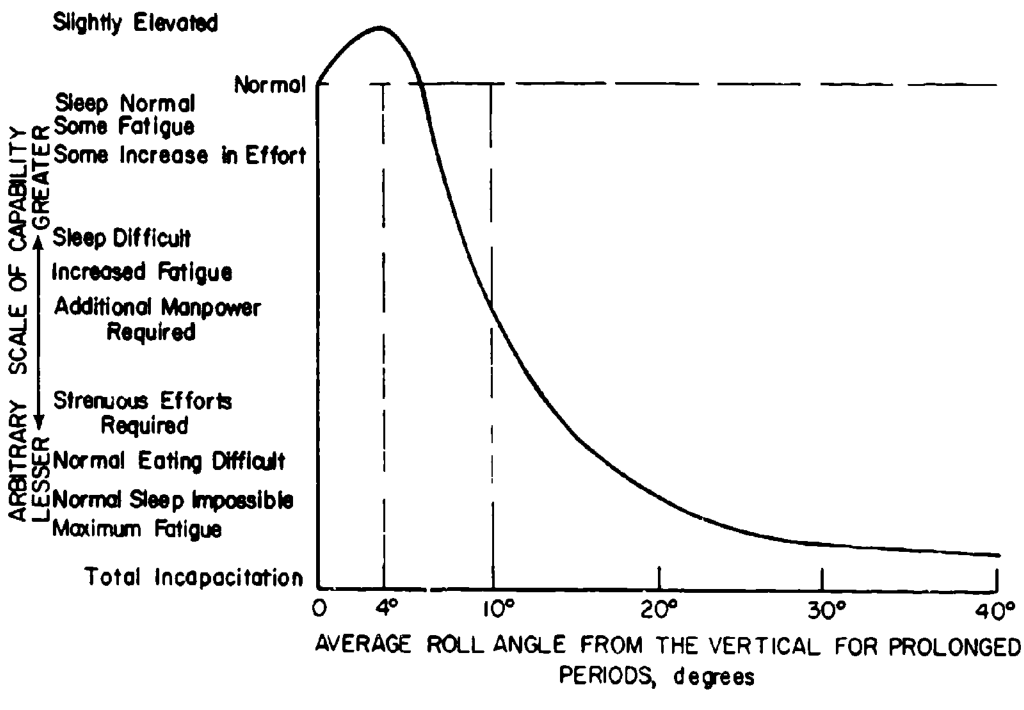

Figure 2
Direct Effect of Rolling Environment on Average Personnel Capabilities

The principal recommendation which results from this investigation involves the nature of the righting forces generated by ship-stabilization equipment. They should be proportioned to minimize angular accelerations, especially in the moderate roll spectrum. Strictly from the motor performance point of view, a trade-off function should be generated throughout the roll spectrum between the deleterious effects of higher amplitude roll and the accelerations necessary to reduce that roll.

Since ships on station may heave-to for extensive periods and during these periods on the open sea they broach-to and wallow considerably as the result of swell action, ideal roll stabilization should be effective in this condition.

Also it is recommended that roll-stabilization equipment be installed on any ship which is expected to roll above 10° and on which on-going motor tasks are critical. We are currently conducting another investigation to determine the decrement in human performance in the postmotion period; it is not clear that normal performance requirements can be met by personnel immediately after being exposed to violent motion.

Further investigation is recommended. However, it should be emphasized that any investigation aimed at determining the effects of ship roll on human performance must be extensive and must include equal consideration of the other irrelevant stresses with which roll interacts in the shipboard environment.

Appendix A

Printed Materials Used in Critical Incident and Motivational Data Collection

Scientific Study of Roll

We are evaluating the possibility of incorporating stabilization gear on a ship very much like your own, which has a certain roll rate. We think that perhaps people who are unaccustomed to the violent motion of the sea will form a part of the crew and we are interested in determining what effects certain kinds of motions, caused by the changing sea states, will have on their performance. We would like to have your help. Because of your experience and the fact that you are assigned to this ship, we consider that you are in the best position to know about these kinds of things and we would appreciate your cooperation on how these conditions affect your performance. In order to simplify the task we would like you to pay special attention to your own performance during the time you are on watch, at your jobs, relaxing, or eating - and tell us how what you are doing was changed by the motion of the ship; for example, if you were sitting down at a desk or table writing and the motion of the ship caused you to break the pencil tip or if you were fixing something and the ship's motion caused you to stop or slowed you down because you knew if you continued doing what you were doing, the ships motion would cause you to make a mistake. Please remember approximately what time this happened and how this happening made you feel. Also, tell us when the ship's motion actually caused you to make a mistake, what you were doing, and what the mistake was. To make this a simple procedure, we will provide you with a sheet of paper on which you can tell us about these happenings. You will use a code name of your own choosing and every bit of information will be kept strictly confidential and used only for scientific purposes by us.

We thank you for your attention and ask that you feel free to ask us questions at any time.

Dictionary of Adjective Check List (ACL) Meaning

The ACL is designed to sample your present moods, emotions and motivations. For this reason we cannot use any meaning in dictionaries, but only those applying to moods, emotions and motivations as they may now be present in you. In the case of each adjective, you check it if your answer is "yes" to the phrase, "I now feel active," "I now feel keyed-up," "I now feel drowsy," etc.

Several of the adjectives have more than one mood or emotional meaning. Please use only the meaning we specify below.

Only in rare cases are the definitions listed below exact synonyms. They are meant only as guides to the approximate meaning. Only those words are defined which might often cause trouble. If you are in doubt about other words, please ask one of us.

9.	apprehensive	uneasy or fearful about something that may happen
10.	assertive	inclined to express and press your ideas
12.	belligerent	tendency to be quarrelsome, to disagree aggressively
16.	brooding	pessimistically preoccupied
21.	cautious	wary
22.	changeable	likely to go from one mood to another; emotionally variable
24.	close-mouthed	uncommunicative, don't feel like talking
31.	defiant	a chip on the shoulder, aggressive or cocky opposition
32.	depressed	blue, dejected
33.	detached	aloof, apart from events, not personally involved
38.	doubtful	unsure, uncertain
43.	dubious	skeptical, slightly suspicious
51.	emotional	easily aroused to emotion, having a high level of emotions
53.	engrossed	absorbed, involved in present activities or concerns
61.	genial	relaxed, cheerful and happy
67.	hostile	antagonistic, unfriendly
68.	humorous	witty
71.	indifferent	emotionally unmoved by events
79.	lackadaisical	without energy or ambition
80.	languid	listlessly relaxed
85.	masterful	powerful, able to control
86.	mischievous	prankish or teasing
87.	nauseated	sick at the stomach
89.	nonchalant	casually unconcerned
91.	optimistic	looking on the bright side of things
98.	remorseful	feeling sorry about one or more of ones actions
99.	resourceful	ingenious and capable of meeting problems
114.	suspicious	distrustful
130.	withdrawn	retracted into oneself, unsociable

Code Name ________________

Date ________________

Hours Covered ________________

List all of the things you were doing that were affected or changed by the motion of the ship

Describe what happened in each case:

Describe where on the ship each of these things happened:

Check one:

During these happenings, the motion of the ship:

___ caused me to work extra hard to do what was otherwise normal

___ did not affect my performance in any way

___ caused me to slow down what I was doing

___ caused me to make simple mistakes

___ caused me to be more cautious

The ship's motion during this last period can best be described by:

____violent motion

Specify which: heavy pitch
heavy roll
heavy heave

____calm motion

____jerky motion (unable to get ready for motion)

Have you taken any drugs or medications of any kind in the past period?

Yes____No____. If yes, were they

1) Sedative or tranquilizer ____________
2) Analgesic (aspirin) ____________
3) Anti-motion sickness remedy (anti-histamine) ____________
4) Other, (Specify) ____________

How many hours sleep did you have last night?____Was this sufficient?________

Insufficient? ________

Do you usually expect to perform better____less well____same____________
as an average person?

This following list gives you a chance to compare how you feel now with how you felt during the time that the ship's motion bothered your performance. Please go through the list and show whether you felt more that way during the time you were bothered, or feel more that way now. Please answer <u>every</u> item.

ANSWER EVERY ITEM

1. Active - energetic	before	now	17. Grouchy - irritable	before	now
2. Angry - annoyed	before	now	18. Humorous - witty	before	now
3. Anxious - fearful	before	now	19. Impatient - snappish	before	now
4. Bored - uninterested	before	now	20. Industrious - work-oriented	before	now
5. Cheerful - happy	before	now	21. Intoxicated - lightheaded	before	now
6. Decisive - capable	before	now	22. Jittery - nervous	before	now
7. Confused - disorganized	before	now	23. Optimistic - high-spirited	before	now
8. Disturbed - upset	before	now	24. Pain - discomfort	before	now
9. Downhearted - sad	before	now	25. Quiet - peaceful	before	now
10. Drowsy - sleepy	before	now	26. Reckless - uninhibited	before	now
11. Dull - sluggish	before	now	27. Resentful - indignant	before	now
12. Easygoing - relaxed	before	now	28. Self-confident - courageous	before	now
13. Egotistic - boastful	before	now	29. Self-conscious - timid	before	now
14. Effective - efficient	before	now	30. Sympathetic - considerate	before	now
15. Genial - friendly	before	now	31. Talkative - chatty	before	now
16. Gloomy - blue	before	now	32. Tired - washed-out	before	now

Which way of feeling did you like better ?______before______now

Please check here to indicate that you have answered every item.______

Completing this list today was: Difficult____Moderately difficult____Moderately easy_____

Easy_____

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13. ABSTRACT

This study examines in an operational setting the hypothesis that human performance is significantly affected by ship's roll. Particular attention is paid to the nature and effects of roll stabilization equipment. The hypothesis is expanded to include the broad spectrum of human performance and the more subtle aspects of ship's motion.

Notable findings include:

- Ship motion causes an irrelevant stress on crew members.
- Some irrelevant stress may actually be beneficial.
- The effect of roll stabilization equipment is diphasic; it reduces intolerable roll amplitudes but tends to induce higher linear accelerations.
- Roll stabilization should be active from dead-in-water through flank speed since mission requirements include extensive operations at low speeds.

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	ROLE	WT	ROLE	WT	ROLE	WT
Incidents						
Roll						
Mass						
Balance						
Accelerations						
Motor tasks						
Cerebral tasks						
Variables						
Correlation						
Environment						
Phychophysical performance factor						
Irrelevant stress						
Fatigue						
Jolts						

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